

2 - RIPARIAN BUFFER FUNCTIONS AND VALUES

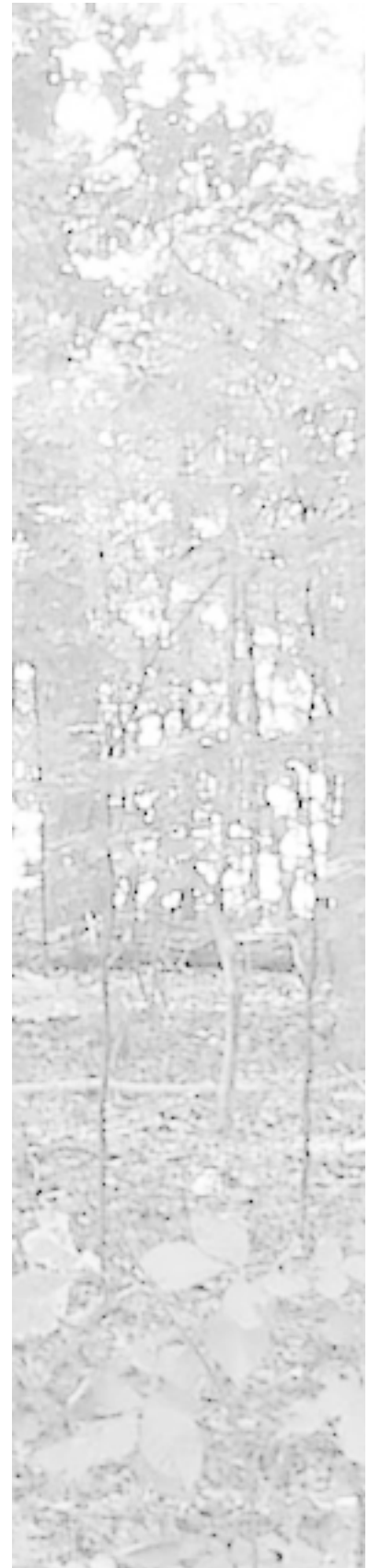
Vegetated riparian buffers are one of the most functionally beneficial and biologically diverse systems that also provide services of great economic and social value. Benefits derived from vegetated riparian buffers, especially forested buffers, include water quality enhancement, stormwater and floodwater management, stream bank and shoreline stabilization, water temperature modification, wildlife habitat protection, and absorption of airborne pollutants. These benefits can translate into increased quality of life and real savings for the community.

Riparian buffers are complex hydrologic and ecological areas that are transitional zones between the surface waters and the upland areas. Although initially thought of as agricultural best management practices, or BMPs, their multifunctional abilities are becoming better appreciated. Traditionally, BMPs were primarily used to control the quantity and quality of stormwater runoff for erosion and sediment, but did not necessarily address issues related to the effects of infiltration and the quality of ground water. A buffer's value lies not only in the ability to moderate erosion and sedimentation, but also in the ability to improve water quality in ground water and surface water runoff, increase the base flow of streams, and provide a biologically diverse habitat.

Buffers may also serve as attractions for tourists and community members, becoming greenways and recreation areas for hikers, birders, photographers, fishermen, picnickers and other outdoor enthusiasts. The influx of visitors to the community can spur an expansion of the local economy from tourism and accessory businesses. These corridors increase the aesthetic appearance of a community, enhance property values, and increase local tax revenues.

WATER QUALITY BENEFITS

Riparian buffers are noted for their ability to protect or enhance water quality. A vegetated riparian zone can trap sediment, and reduce or remove nutrients and other chemicals from precipitation, surface waters and ground waters. The percentage of removal of these contaminants depends upon the width of the buffer, the composition of the vegetation in the buffer, the type of soil present,



the topography, the geohydrologic setting and climatic variables within the region.

Erosion and Sediment Control

A small amount of erosion and sedimentation occur naturally within any hydrologic system, but when land is developed upland of a Resource Protection Area (RPA), it can intensify, causing damage to all areas of the ecological system. A riparian buffer, while not capable of preventing upland erosion, can mitigate the effects on water quality from upland sources of sediment.

Sediment can come from either upland sources or from the stream itself. In general, the greatest sources of sediment are row crop agricultural fields and construction activities. Livestock that are permitted direct access to streams can cause bank destabilization and erosion, adding to the sediment load, as can some timber harvesting practices, especially when a site is clear-cut or forest roads are poorly maintained. Instream dredging activities for mineral resources can also contribute to channel degradation and downstream turbidity.

Sediment that reaches surface waters is a pollutant that can be hazardous to the aquatic plant and animal life. It increases the turbidity of the water, increases the scouring effect of moving water and can transport sediment-bound chemical pollutants, such as phosphorus. The increased turbidity can have a direct effect on fish that are too sensitive to survive the excess suspended sediment. When suspended sediments settle to the bottom of the channel, critical habitat for fish and other species may be degraded. Benthic organisms can suffocate, depleting the food supply for many fish, and reducing the abundance of filter-feeding organisms that help clean the water. The turbidity also prevents sufficient light from reaching submerged aquatic vegetation (SAV) and benthic algae necessary as food for the various forms of aquatic life.

Buffers can reduce the quantity of surface runoff reaching a stream by enhancing infiltration and ground water recharge, which in turn reduces peak streamflows and helps to prevent increased velocity within the channel bed. Channel erosion occurs when the velocity of the water in the stream causes it to cut into the banks and channel. This is a major source of stream sediment.¹ The water and suspended sediment scours the stream channel and undercuts banks making them unstable and causing them to slump into the stream. In urbanized areas, intensified streambed flow

results from decreased infiltration in the watershed due to increased impervious area and the concentration of flow off impervious surfaces into man-made channels before reaching streams. Channelization increases stream velocity causing greater scouring ability.

Riparian buffers help to reduce the stream sedimentation in several ways. A buffer may keep the land disturbing activity far enough back from the water feature that the disturbance does not directly affect the banks. Buffers can also reduce the speed and volume of overland runoff through enhanced infiltration. The vegetation, roots, leaf litter and detritus can trap sediment from surface runoff before it reaches the water. The vegetation, particularly their roots, helps stabilize stream banks preventing their failure, and also provides woody debris within the stream that helps trap sediment. During floods, the buffer moderates the velocity of the storm flow that surges onto the floodplain, reducing scouring, and allowing the sediment to settle out and be deposited on land.

The width of the buffer is the primary determining factor for its effectiveness. However, soil and slopes can vary the efficiency of the buffer for removing sediment. In Virginia, a buffer width of 100-feet has been deemed sufficient to protect water quality through the removal of sediment and nutrients. Additionally, on-site sediment control is important in source areas such as agricultural fields and construction sites to prevent excessive loadings from reaching the buffer.

In order for vegetation to be effective at retaining the stream or shore bank, it should have a strong, deep root structure to hold the soil. Woody vegetation with its spreading roots is best for stabilizing banks and deep-rooted warm-season grasses are effective for shore bank erosion control. Structural solutions such as riprap or concrete may halt the erosion on site, but may increase erosion downstream. Such solutions also lack the ecological benefits that wooded solutions have for habitat both in and out of the stream, lake or other water body. (See Chapter 3.4 for more information on shoreline management).

The effectiveness of the buffer also requires that it be continuous along streams and rivers. It is also important for these buffers to be maintained so that rills, gullies or gaps do not develop, allowing runoff to bypass the sediment trapping ability of the buffer. Maintaining a shallow sheet flow into and through the buffer is imperative for its effectiveness. Riparian buffers are especially important on headwater and small streams that have the greatest

amount of water-land interaction and, therefore, have the most opportunities for gaining and transporting sediment. Once that sediment has entered the system it can be continually re-suspended as it travels downstream.

Nutrient and Chemical Control

Nutrients such as phosphorus and nitrogen and chemicals such as pesticides can lead to many changes in the ecology of the water features as well as degrade the quality of potable water used by humans. Although there are natural sources of nitrogen and phosphorus, human activity has accelerated the rate and amount of nutrients reaching ground and surface waters. In rural areas, agriculture is generally the leading contributor of nutrients, from row crops and livestock operations, but residential lawn fertilization and on-site sewage systems contribute a significant amount of nutrients and pathogens. In urban areas the runoff from turfgrass and impervious areas are the principal sources of nutrients. Pesticides entering the system can be toxic to organisms at either lethal levels or at levels that cause sub-lethal deleterious effects.

Nitrogen and phosphorus are two major contributors to the degradation of the aquatic environment in the Chesapeake Bay. Both contribute to eutrophication, a condition resulting from the overabundance of algae. The algal blooms have several consequences. The algae itself consumes oxygen and nutrients that could have been used by other organisms and may release toxins that are directly harmful to other aquatic life. The increase in algae diminishes the amount of light available to submerged aquatic vegetation for photosynthesis, so the SAV declines. The subsequent loss of SAV beds eliminates habitat and food for numerous other species. As the algae die the excess amount of decaying organic matter consumes oxygen so that it is not available for other organisms.

Non-point sources of phosphorus and nitrogen include agricultural and urban fertilization, atmospheric deposition, animal waste from pastures and feedlots, and sewage from septic system drainage fields and leaking sewer pipes.

Phosphorus

Phosphorus is essential to plants for the conversion of sunlight into energy for their use. It has long been known to be the

principle cause of eutrophication in lakes and other freshwater systems, and was removed from laundry detergent for that reason. In estuarine waters, typically affected by nitrogen, seasonal shifts have shown phosphorus to be a factor. Continued phosphorus input from erosion, fertilizer, manure applications and other wastewater sources still disrupts aquatic environments by promoting algal blooms.

Much of the surface application of phosphorus that is not taken up by crops or turfgrass enters surface waters attached to sediment and organic material and is transported in runoff after storm events.² Because riparian buffers can act to remove sediment from runoff, a buffer that is effective in removing sediment should also remove the majority of total phosphorus. Indeed most phosphorus is retained in a buffer, and the retention percentage increases with the width of the buffer, assuming the inflow is shallow and uniform.

However, long-term retention of phosphorus may be limited. Unlike nitrogen, which can be released into the atmosphere through denitrification, phosphorus is used by vegetation, adsorbed by clay particles, precipitated with metals or exported into the groundwater.³ Soils can become saturated with phosphorus, unable to retain additional soluble phosphorus, and vegetation may reach a limit to what it will retain. At a minimum, a riparian buffer can keep the phosphorus producing activity away from the stream. With other tools aimed at reducing the source of phosphorus, a buffer will help regulate the flow of phosphorus that does reach it.

Nitrogen

Non-point sources of nitrogen are the same as those for phosphorus. There are various organic and inorganic forms of nitrogen, some of which can readily change to another form under the right conditions, nitrate and ammonium being two forms that have potential for harm. Nitrate is potentially toxic to infants (mammals, including humans) if it reaches a 10mg/L concentration, and ammonium is toxic to many aquatic organisms. Both can be difficult and expensive to remove from drinking water in treatment systems.⁴

Nitrogen is generally the principle nutrient causing eutrophication in brackish waters such as the Chesapeake Bay. An over abundance of nitrogen entering the water contributes to algal blooms that block light to underwater plants, absorb nutrients and

release toxins. As the algae die, the decaying matter depletes the water of oxygen causing eutrophication. Dense mats of dead organic matter can sink to the bottom suffocating the bottom-feeding organisms that are the source of food for other aquatic life.

Riparian buffers can have a significant impact on the removal of nitrogen, especially if they have a mix of plants including trees, shrubs and tall native grasses. A vegetated buffer is important for both the control of surface runoff and subsurface flow. Nitrate, a highly soluble form of nitrogen can readily move into ground water and be transported to surface waters. Most nitrogen enters the buffer dissolved in the ground water. According to studies done by the U.S. Geological Survey's Chesapeake Bay Ecosystem Program, "...about half of the water flowing into the Bay originates from groundwater, which carries about half of the nitrogen that enters the Chesapeake."⁵ Trees, shrubs and tall native grasses that have significant deep roots extending into the sub-surface waters are important for protecting ground water that has traveled from great distances. So, even if stormwater systems circumvent the buffer, the buffer remains important for subsurface nitrogen removal.

There are several ways that a buffer can remove nitrogen passing through it: uptake by vegetation and denitrification are the primary mechanisms. Nitrogen can also be used by some soil microbes or adsorbed by soil particles. If the nitrogen flows through the root zone of a forested buffer, significant nitrogen removal can occur, primarily from denitrification. However, there are seasonal variations and different levels of removal depending on the vegetation, type of soil and degree of saturation.

Plants can take up a large amount of nitrogen when they are producing new growth, but a significant amount is returned to the soil when leaves die and decay on the ground. However, this nitrogen is available for further processing within the buffer system. Under certain circumstances denitrification is the primary process for permanent nitrogen removal in buffer areas. Denitrification is the conversion of nitrate to nitrogen gas that is released into the atmosphere. It requires a high or perched water table, anaerobic conditions alternating with aerobic conditions, available carbon and denitrifying bacteria.⁶ Forested buffers supply both carbon, through leaf litter and detritus, and the denitrifying bacteria. Perched or seasonal high water tables can create the proper anaerobic conditions for denitrification to occur. A forested buffer will also continue processing nitrogen during the winter, unlike some types of vegetation that may go dormant.

While an herbaceous buffer can do significant good by slowing surface runoff and trapping sediment, the most significant gains for removal of nitrogen come from a mixed forested buffer of woody plants. The deep roots entering the ground water supply the necessary carbon and harbor bacteria in the soil for denitrification, so nitrogen can be permanently removed from the system. Much of the nitrogen in a system has entered the ground water quite a distance away from the surface waters. These underground aquifers then slowly carry the nitrogen and other contaminants to surface waters. So, even in an urban situation where most of the stormwater from adjacent properties is piped through a buffer, it still has an important role in pollutant removal. Woody vegetation in these buffers can be of significant value in removing ground water contaminants before they reach surface waters.

Other contaminants

Other contaminants such as pathogens, pesticides, heavy metals, and excessive organic matter can cause degradation in aquatic systems as well. Animal and human waste can supply pathogens and organic matter to surface water. Pesticides, like fertilizer, are applied to agricultural fields and residential lawns. Heavy metals are usually associated with transportation systems and industrial activities, but can enter systems through surface runoff from urban areas.

Pathogenic (bacteria, protozoans, viruses, etc.) contamination is a major pollutant whose survivability increases with high nutrient levels and suspended solids. Pathogens may die off quickly when they enter surface water, but they may become adsorbed by sediments or organic matter in the water and survive longer. These disease-producing pathogens can either harm aquatic life, be passed onto humans when contaminated fish and shellfish are consumed, or by direct contact with the water.⁷ Buffers can trap waste from surface waters, preventing it from reaching water features.

Toxins may have immediate effects if present in large amounts, or may cause non-lethal disruptions in the life cycle of organisms such as increasing susceptibility to disease, or disruption of the reproductive or neurological systems. Humans can be affected by toxins in drinking water, fish or shellfish, or by direct contact in water. Pesticides, heavy metals, and hydrocarbons are all examples of toxins that may reach waters and persist in sediment for years. Once they are in the system, floods, boating, dredging,

or construction can release them from the bottom causing continuous environmental disruption.

Riparian buffers help minimize pesticide problems by keeping pesticide application away from the water feature, preventing direct contamination and reducing the risk of drift. They can be useful for the reduction of toxins from surface runoff as well. Many pesticides and herbicides are retained in the buffer decomposing over time, and many heavy metals can be bound to soil particles. As with nitrogen and phosphorus, the dense vegetative cover and litter layers encourage infiltration of pesticides. The dense root biomass and layers of organic matter support a rich soil capable of transforming dissolved chemicals through enhanced microbial activity.⁸

HYDROLOGIC BENEFITS

The urbanization of a watershed has several effects on the hydrology of an area. The development of an area alters the natural drainage pattern as roads and buildings are fit onto the landscape. This also increases the amount of impervious surface that then amplifies the quantity of stormwater runoff that is concentrated before being released into the existing drainage system. In addition to augmenting the runoff quantity, the concentration of water boosts the speed at which it travels, multiplying the scouring power in surface streams and rivers. Additionally, as most of the existing natural vegetated areas are denuded, local rises in the water table can stress existing deep-rooted trees.

The rapid transport of water away from the land surface by stormwater conveyance systems reduces the amount of water that seeps into the soil and recharges the ground water system. An important function of the riparian buffer is to slow the rate of runoff, increasing the potential for infiltration. The recharging of the ground water is important for maintaining wells and supplying the baseflow waters that feed streams. The vegetation is important for maintaining a uniform flow of water through the buffer allowing longer detention times for pollutant transformation or removal. A uniform flow also helps protect stream and shoreline banks from erosion. During floods, the trunks, stems, twigs, and woody debris within the forested buffers provide a further advantage by modifying the speed of water flow through the floodplain. This reduction in the speed of water flow helps to encourage the settling of sediment and associated contaminants.

HABITAT BENEFITS

Forested buffers provide benefits to habitat both instream and on land. Aquatic habitats are affected most profoundly by excess sediment, as discussed earlier. A primary benefit of riparian buffers is their preventative ability in limiting sediment, nutrients, and toxins from reaching the water and degrading aquatic habitat. A forested buffer can provide additional habitat enhancements to the aquatic system by providing food, shade, and woody debris or snags for shelter. On land, the terrestrial habitat benefits from the ready availability of water, the abundant food supplied by riparian vegetation and the variety of cover provided by trees and shrubs to support a diverse selection of organisms.

Healthy aquatic habitats depend upon clean water. Certain microorganisms and invertebrates at the bottom of the food chain require a high quality of water to survive. As water quality declines and these organisms disappear, valuable resources dependent upon those organisms for food or ecological services also decline.

When the temperature of a stream rises due to the lack of shade provided by a forested buffer, it may no longer support valuable resources. The smaller tidal and non-tidal freshwater streams in the Tidewater area are important breeding grounds and nursery habitat for economically and ecologically important species of shad and herring. These resources depend upon an intact riparian corridor and the benefits, such as lower water temperatures, that a riparian canopy provides.⁹

Other resources such as SAV or oysters depend upon an adequate buffer to prevent sediment, nutrients, and other toxic chemicals from reaching the water and degrading their habitat to such an extent that they cannot thrive. The water quality functions of a vegetated riparian buffer can help maintain a supply of clean water vital for a healthy habitat.

Aquatic Habitats

Terrestrial inputs to small streams are the predominant source of food for aquatic organisms. Microorganisms that form the bottom of the food chain break down the leaves, twigs, fruits, nuts, flowers and insects that fall into the stream. The nutrients derived from detritus contributed by the forest provide food for aquatic plants as well. The invertebrates that depend on organic debris and microorganisms are in turn important sources of food for

fish. The seasonal increase in organic material in spring and fall coincide with the increase in insects and with fish reproduction and growth.¹⁰ If the woody vegetation were removed from the buffer it would affect the abundance and types of insects, thereby affecting the species of fish present. In large rivers and streams, the edge of the channel provides habitat for the smaller fish. They depend on the insects and debris, which falls from the riparian area, for food.

A forested buffer provides environmental enhancements as well, through moderating stream flow and velocity, providing shade, and large woody debris. As discussed earlier, the buffer reduces the velocity of runoff and absorbs much of the runoff water. Natural seasonal flow patterns have an affect on the life cycles of many aquatic organisms and water levels can affect breeding activity. Velocity affects the amount of oxygen and organic material that is present and whether or not a species can move up and down the stream.¹¹ Forested buffers, because of their absorptive capacity, moderate the effects of flooding as well as the consequences of drought. During flooding they may also provide habitat for breeding populations. Floodwaters may pick up debris, organic matter and small organisms. These nutrients return to the stream channel when the water recedes, providing food for aquatic plants and microorganisms that in turn feed the larger fish.

Trees dropping large woody debris into a stream promote a variety of habitat for a diverse number of aquatic organisms. Large logs help create pools, riffles, or still backwaters that function as places for fish to rest and juveniles to seek shelter. They supply cover from overhead predators and sunning spots for reptiles and amphibians. Logs also provide surface habitats for invertebrates to colonize. Woody debris can capture twigs, leaves, and other organic food items, such as seeds, or provide surface areas for invertebrates to colonize. Benthic populations are greater in areas with ample woody debris and snags to create habitat for reproduction.

The canopy of a forested buffer has a direct affect on the light and temperature of the stream water. The amount of light that reaches the stream is important for the rate of plant and algae growth. Sunlight hitting a stream raises the water temperature with many biological consequences. A higher temperature can increase decomposition, decrease the amount of oxygen in the water and increase the amount of nutrients released from suspended sediments.¹² The higher temperature and greater amount of light can encourage the growth of algae and parasitic bacteria while creating an environment that supports a less diverse community. Many

species of fish can only survive within a specific range of temperatures. Higher temperatures will prevent some species from thriving and stress others beyond survival.

Terrestrial Habitat

The plant communities of riparian areas are highly productive and typically contain a wide diversity of species. The regular input of nutrients and organic material, combined with the typically rich, moist soil supports a wider variety of both plants and animals than the surrounding lands upland of the riparian area. They also provide a variety of edge conditions along both the stream and adjacent land providing multiple habitats for wildlife.

Riparian buffers can provide habitat for an equally diverse animal community depending on the surrounding land uses. The complex plant community of a natural buffer provides water, food and shelter for both permanent and migrating species. The availability of food from seeds, fruits, buds and twigs to insects and small mammals makes the buffer an important source of food. The variety and complexity of wooded buffers supplies numerous opportunities for shelter for birds and small animals. Riparian areas provide corridors of habitat within agricultural settings and may provide the only natural areas in urban landscapes.

The particular mix of vegetative species may determine the density and diversity of animals within the buffer, but a greater diversity of wildlife is present in forested buffers because of the more complex habitat. In landscapes lacking large forests, a forested buffer may provide habitat for large mammals such as deer or other mammals such as beaver, raccoon, and muskrat. As areas surrounding urban development expand, the importance of riparian forested buffers increases. The remaining riparian forests may be the only vegetated corridors remaining for wildlife to travel for food or to find a mate.

Small mammals such as squirrels, mice, voles, shrews, and chipmunks are more likely to favor a riparian forested buffer than adjacent uplands because of a greater diversity of trees and shrubs for food and shelter. Reptiles and amphibians also favor riparian buffers, especially along smaller streams where many spend their entire lives. Birds in agricultural areas favor forested buffers for habitat. The diversity of bird species increases in the buffer even when a bottomland forest area is adjacent to existing forests.¹³ Wider buffers (164 ft to 328 ft.) are more likely to provide breeding habitat for neo-tropical migratory birds as well.¹⁴

OTHER BENEFITS

Many of the advantages that natural systems derive from riparian buffers are equally important for the economic, health, aesthetic or recreational benefits that humans can receive from them. One obvious benefit is the retention of floodwaters within a flood plain, preventing the loss of property and life. The reduction of stormwater runoff can translate into millions saved in stormwater management structures and erosion control measures. An intact, forested buffer can also hold soil in place and help retain the natural hydrology behind a shoreline bank. This can be invaluable in the prevention of shoreline erosion and failure, which might otherwise necessitate an expensive structural solution.

In addition to providing aesthetic value to property, wooded lots have a higher resale value. Summer shade from deciduous trees can reduce cooling costs up to 50%, while blockage of winter winds by evergreens can save heating costs up to 20%.¹⁵ A forested buffer has additional value for air quality since trees can remove many pollutants from the atmosphere as well. Pollutants such as carbon monoxide, sulfur dioxide, ozone and nitrogen dioxide are introduced into the air from burning fossil fuels. These chemicals can be deposited on the water adding to the pollutant load, but trees can be an important tool in their removal as well.

Fish streams require surface shading provided by forest buffers, otherwise the fish populations diminish. Anglers drawn to productive streams provide millions to the state and local economies as do game hunters after deer, waterfowl and other small game that inhabit buffer corridors and the waters they protect. The quality of water directly affects the breeding grounds and habitat of many of our commercial fin and shellfish that support a large commercial fishing industry. In Virginia, the water quality standards include a strict fecal coliform limit for its shellfish waters. The economic benefits may also include the use of the buffer as managed forest to produce lumber or other products such as nuts, berries or mushrooms.

The qualities of a buffer that increase the quality of life for residents in an area may also increase tourist visitation bringing tourist dollars. Recreational possibilities increase with abundant forested riparian buffers. The higher quality habitat of a forested buffer ensures the presence of a greater and more desirable amount

of sports fish. A wider forested buffer brings an increase in the diversity of birds for bird watchers, a fast growing segment of recreational tourists. Farmers have come to appreciate the diversity of small game that increases as forested buffers are restored or expanded.

Riparian buffers offer opportunities for the development of community greenway trails connecting parks or other neighborhood open areas. Paths for hikers, bicyclists, skaters, or even equestrian trails can add to a community's quality of life. Safe paths may connect neighborhoods to schools and provide educational opportunities for science classes and nature clubs. Just the aesthetic qualities alone can add value to property providing seasonal changes, shade in summer, flowers and birds in spring, and fall color.

SUMMARY

Riparian buffers fulfill many functions on several different levels. While required by the Chesapeake Bay Preservation Act for water quality benefits, the advantages realized by a natural or established forested buffer go well beyond clean water, erosion control and control of runoff. The presence of properly vegetated buffers provides biologically diverse habitats both in the water and on land. They are complex ecological systems that connect the upland areas with surface waters providing a transitional area through which both the surface and ground waters flow. Protecting riparian buffers protects human health and welfare by protecting water supplies, and may create economic advantages through increased property values.

The ability of the buffer to reduce the speed and volume of stormwaters and floodwaters encourages their retention in the soil helping prevent the loss of property and lives. In slowing the progress of the floodwaters, the buffer also reduces the velocity of the stream, allowing sediment and attached nutrients and toxins to filter out and settle. The woody vegetation with associated litter slows stormwater runoff, reducing erosion and permitting infiltration of water to recharge the ground water system. Detention within the buffer of both surface and ground waters allows the retention or transformation of pollutants before they can reach open waters. The vegetation along streams and coastal shorelines hold the banks in place with their roots, minimizing the addition of further sedimen-

tation through bank failure.

As part of greenways and open space within a community, riparian forest buffers provide numerous opportunities for recreation and education. Hikers, birdwatchers, and bicyclists can all enjoy the variety of landscapes and habitats in a buffer. Sporting enthusiasts also enjoy the fishing and small game opportunities available in forested buffers. As part of the quality of life in a community, a system of buffers may add to the economy of an area as well through aesthetics and land value.

Riparian forest buffers add a variety of benefits to a watershed and its adjacent communities. While its primary value is derived from its water quality, flood control and erosion control functions, fortunate side effects of a functioning buffer are the benefits to fisheries and wildlife and to the quality of life for communities' citizens.

¹ Wenger, S. (March 5, 1999) *A review of the scientific literature on riparian buffer width, extent and vegetation*. Rev. Office of Public Outreach, Institute of Ecology, University of Georgia. p.18.

² Klapproth, J.C. & Johnson, J. E. (2000). *Understanding the science behind riparian forest buffers: Effects on water quality*. Virginia Cooperative Extension Service Publication Number 420-151. p.3.

³ Wenger. p. 22.

⁴ Wenger. p. 24.

⁵ The Bay Journal. (June 1998). "Lag time of groundwater dampens hope for fast Bay cleanup." Dec. 17, 02. p.1.

⁶ Klapproth, J. C. & Johnson, J. E. (2000). *Understanding the science behind riparian forest buffers: Effects on water quality*. Virginia Cooperative Extension Service Publication Number 420-151. p.4.

⁷ Klapproth. *Effects on plants*. p.6.

⁸ Brinson, M. M. (2002). *Riparian Areas: Functions and strategies for management*. National Academy Press. p.74.

⁹ Dr. Greg C. Garman, e-mail to author, May 20, 2003.

¹⁰ Klapproth, J. C. & Johnson, J. E. (2000). *Understanding the science behind riparian forest buffers: Effects on plant and animal communities*. Virginia Cooperative Extension Service Publication Number 420-152. p. 8.

¹¹ Klapproth. *Effects on plants*. p.9.

¹² Klapproth. *Effects on plants*. p.9.

¹³ Wenger. p. 37.